From rags to riches and back again: fluctuations in the Green and Golden Bell Frog *Litoria aurea* population at Nowra on the south coast of New South Wales

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ABSTRACT

Systematic (time constrained) and targeted surveys were conducted from 1996-2014 for the green and golden bell frog *Litoria aurea* on the Crookhaven River floodplain, east of Nowra on the south coast of New South Wales. In April 2008, a large number of metamorphlings were observed at Brundee Swamp Nature Reserve. This was followed by a significant recruitment of frogs so that by February 2010 *L. aurea* were recorded breeding nearby in Worrigee and Terara Swamps. At the end of April 2010 tens of thousands of metamorphling *L. aurea* dispersed from these wetlands across the floodplain. So-called explosive breeding events have been reported for this species before but never have they been documented. In December 2010 *L. aurea* again bred in Worrigee (and presumably Terara Swamp) and in early April 2011 adult and sub-adult animals appeared to have dispersed a distance of approximately 4 km south-west and 11 km to the south-east of Brundee Swamp. This expansion in distribution and abundance resulted in the recolonisation of historic *L. aurea* sites at Culburra and colonisation of other parts of the catchments where the species was never previously recorded. The recovery was not sustained and from March 2013 to March 2014 the species had declined in abundance and distribution. Most of the recorded breeding occurred in ephemeral wetlands: dispersal from these sites involved movements over highly modified rural and urban landscapes. Refuge sites populated outside the breeding events were strongly associated with stands of Cumbungi *Typha* spp. in drainage systems. These observations illustrate that historic and potential habitat of *L. aurea* should not be disregarded, even if the species has been absent for a considerable period. More effective management of *L. aurea* by government agencies requires a whole of landscape approach.

Key words: Green and Golden Bell Frog, population recovery and decline, Nowra.

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Introduction

Rapid declines in species of amphibians such as the Green and Golden Bell Frog *Litoria aurea* underline the need for long-term systematic monitoring of specific populations (Daly *et al*. 2008). In 1996, *Litoria aurea* was known at only 51 sites within New South Wales (NSW) (White and Pyke 1996), but by 2006 the species had further declined to only 41 sites (White and Pyke 2008). Currently most of these populations are still in decline. As a consequence *L. aurea* remains listed as an endangered species in New South Wales under Schedule 1 of the *Threatened Species Conservation Act, 1995* and is listed Nationally as vulnerable under the *Environment Protection and Biodiversity Conservation Act, 1999*.

The conservation of *L. aurea* is dependent on an adequate understanding of their population ecology (Goldingay and Newell 2005), habitat use (DEC 1995, Pyke and White 2001) and distribution. *Litoria aurea* is known to occur in a wide range of habitats such as natural coastal wetlands, ponds within coastal dune swales, within quarries, dams and ponds (Pyke *et al*. 2002). Populations often use newly-formed or occasionally flooded sites for breeding (Daly 1995, Daly *et al*. 2008) making it difficult to ascertain the size of a population as frogs may gather for a limited time at a breeding site and then disperse. The variation in the size and scale of habitats (small ponds to large wetlands) that *L. aurea* use also presents a problem in adopting systematic methods to determine population densities. The current study area included land that occasionally floods after prolonged and /or intense rainfall, which may be used by *L. aurea* for breeding. I surveyed a portion of the population of *L. aurea* at Brundee Swamp Nature Reserve (NR), Saltwater Swamp NR, Worrigee NR, Jervis Bay National Park (NP) and elsewhere on the Crookhaven River floodplain on the south coast of New South Wales (NSW) using a variety of methods from 1996 to 2014.

The aim of the surveys was to assess the population size, distribution breeding activity and recruitment to metamorphling stage of the species within the Crookhaven River floodplain. The study also related detection rates to environmental variables, such as season and rainfall. For a species such as *Litoria aurea*, that at various times utilises a range of breeding sites that are physically separated from dispersal and refuge habitat, it is important to understand the habitats used in natural and anthropogenic environments so that more effective conservation strategies can be formulated.

Methods

Study area

Terara Swamp and other freehold land in the Crookhaven River floodplain

Historically the native vegetation on freehold land within Terara Swamp and the majority of the Crookhaven River floodplain was Swamp Oak *Casuarina glauca* forest. This has been highly modified as a result of agricultural activities over the last 100 years. The broad area has little topographic relief and the Crookhaven River – Shoalhaven River floodplain is subject to inundation. To facilitate cattle grazing, wetlands were drained by the installation of drainage channels, initially excavated by early European settlers and expanded in more modern times (Daly 1996, Shoalhaven City Council 1992). Some drainage channels have water control barriers (flood gates) to prevent salt water penetrating their upper reaches (1000's of hectares).

In other areas of the floodplain there are natural drainage lines. Due to unevenness in topography these drainage lines may fill and become isolated ponds, which, during periods of below-average rainfall may dry out. Some of the smaller tributary channels support stands of Cumbungi *Typha* spp. The channels and various farm dams across the floodplain support permanent populations of Plague Minnow *Gambusia holbrooki*, which during periods of flood colonise other areas within the wetlands (pers. obs.).

Details of the reserves and national parks surveyed are provided below. However, surveys also occurred over the broader floodplain on freehold land. In particular, this included Currambene SF and areas around the suburbs of Culburra, Greenwell Point, Nowra and Worrigee.

Brundee Swamp Nature Reserve

Brundee Swamp NR was gazetted in 2001 and covers an area of 227 hectares (Figure 1). The reserve is located about 7 km south-east of Nowra (latitude 34°55'S and longitude 150°39'E) on the edge of the broad, lowland floodplain of the Crookhaven River. The swamp formed as a result of deposition of marine, estuarine and fluvial sediments that infilled old coastal lagoons as sea levels rose at the end of the last glaciation (Dalmazzo *et al.* 2000) some 12,500 ybp. Drainage canals were dug in the lower reaches of Rotten Creek and the Crookhaven River, within and outside the reserve, to drain freehold land. Flood gates were erected to prevent salt water spreading from the Crookhaven River into the wetlands, which are below sea level. Brundee swamp is extensive and during times of flood extends beyond the nature reserve boundaries onto freehold land. Prior to drainage engineering work, large areas of the wetland were inundated with brackish water at high tides, as well as periodical inundation by freshwater. Prior to gazettal, the land was leased for cattle grazing and much of the Swamp Oak forest was cleared. With the gazettal of Brundee Swamp NR there has been extensive regrowth of the Swamp Oak forest.

Saltwater Swamp NR

Saltwater Swamp NR was gazetted in 2001 and covers an area of 214 hectares. The reserve is located about 10 km south-east of Nowra (latitude 34°57'S and longitude 150°40' 30"E) on the edge of the Crookhaven River and like Brundee Swamp also formed as a result of deposition of marine, estuarine and fluvial sediments which infilled old coastal lagoons. Prior to gazettal the wetland was partially cleared and used for grazing. Saltwater Swamp NR has man-made drainage channels.

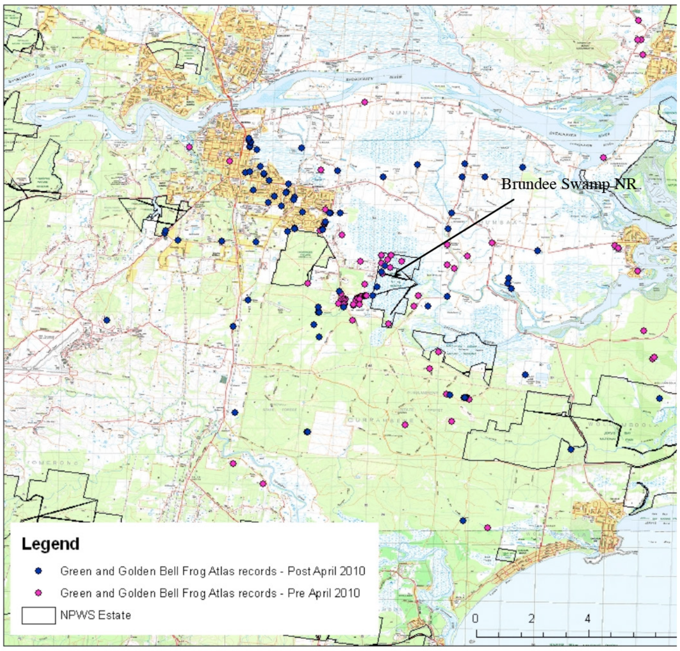
Brundee Swamp NR
Legend
● Green and Golden Bell Frog Atlas records - Post April 2010
● Green and Golden Bell Frog Atlas records - Pre April 2010
▭ NPWS Estate
0
2
4

Figure 1 Location of Brundee Swamp and distribution of Bell Frogs pre and post April 2010 (Figure courtesy NPWS 2011)

Worrigee NR

Worrigee NR was also gazetted in 2001 and covers an area of 230 hectares. The reserve is located about 7 km south-east of Nowra (latitude 34°55'S and longitude 150°37'E) and is also within the catchment of the Crookhaven River. An adjoining area of 384 ha is vested for gazettal. The 1:100 000 soil landscape sheet for the Kiama area (Hazelton 1993) indicates Worrigee NR is on the edge of soils derived from a fluvial source (Crookhaven and Shoalhaven Rivers) and depositional landscape. In Worrigee NR the soil is primarily clay. Prior to gazettal the area was part of the Nowra State Forest (SF) and was used for timber extraction.

Jervis Bay NP

Jervis Bay National Park (4888 ha) is situated ten km south-east of Nowra (Lat 34°57'30", Long 150°44') and was gazetted in 1997. There are a number of disused farm dams in the Copper Cup Point area of the reserve that was historically used for grazing. The park also includes Lake Wollumboola, a shallow semi-saline lagoon, which varies in area from 0-1030 ha (Kinhill Knight 1996). It is the largest semi-saline lagoon in coastal NSW and intermittently opens to the sea, on average once every five years (Blackley *et al.* 1996). The frequency of openings is increased by human intervention. The lake is fed by Coonemia Creek.

Site Selection

The sites selected for assessment varied with respect to access, size and habitat use. Regular monitoring sites were located at dams at Greenwell Point, Currambene SF and drainage channels/ponds at Culburra as these areas were easily accessed and regularly supported populations of *L. aurea*. Sites surveyed within the Reservation system were selected in order to give spatial separation. These sites were either discrete areas within Brundee Swamp NR, along creeks (Jervis Bay NP, Worrigee NR and Saltwater Swamp NR) or dams (Jervis Bay NP). Surveys to assess the distribution of the population occurred over the broader landscape and focused on dams and Cumbungi lined drainage channels.

Habitat

Currently the majority of the land within the Crookhaven floodplain is freehold and used for dairy cattle. The vegetation is mostly pasture but there are remnants of Swamp Oak, Swamp Paperbark *Melaleuca ericifolia* and estuarine saltmarsh including tussock rush *Juncus kraussii australasicus.* There are stands of Cumbungi along some drainage lines that are fenced from cattle. The floodplain has acid sulphate soils.

In Brundee Swamp NR there is extensive area of Swamp Paperbark Forest on the southern third of the swamp (Simpson *et al*. 2006). Cumbungi and Thatch Reed *Phragmites australis* occurs in some areas, particularly close to the drainage canals. Within the previously cleared central area are regenerating stands of Swamp Oak and Swamp Paperbark, however the weed Fleabane (*Erigeron* sp.) is abundant as is the tussock rush *Juncus krausii* (Simpson *et al*. 2006). The canopy attains 10 m in height and is often dense. Prostrate species such as Sea Rocket *Cakile edentula* and *Sarcocornia quinqueflora* are also common and indicate that prior to the installation of the floodgates the area was inundated with salt water. Small areas of forest occur on better drained higher ground and include a mixture of Swamp Mahogany *Eucalyptus robusta*, Spotted Gum *Corymbia maculata* and Blackbutt *Eucalyptus pilularis*.

Saltwater Swamp NR has extensive stands of Swamp Oak, Swamp Paperbark and estuarine saltmarsh including tussock rush. In gaps between dense patches of this rush, there is usually a continuous cover of succulent forbs, including *Selliera radicans, Sarcocornia quinquefaria* and *Lobelia anceps*, and the grass *Lachnagrostis filiformis* (Simpson *et al*. 2006). The adjacent forest includes a mixture of Swamp Mahogany, Spotted Gum and Blackbutt. The canopy may be as high as 25 m in the eucalypt forest and 15 m in the Swamp Oak forest.

Worrigee NR and the proposed extension is dominated by Spotted Gum being the tallest and most abundant species, with Grey Ironbark *Eucalyptus paniculata*, White Stringybark *Eucalyptus globoidea*, Red Bloodwood *Corymbia gummifera* and Grey Gum *E. punctata* occurring as isolated trees or small stands (Jervis Bay Lowlands Shrub/Grass Dry Forest – by Thomas *et al*. 2000). Low lying and poorly drained areas have Woollybutt *E. longifolia* and the Paperbark *Melaleuca decora*. The canopy attains 25 metres in height. The mid-canopy and shrub layers are sparse as a result of fire. The ground cover consists of several species of *Lomandra*. This forest has been heavily logged.

Jervis Bay NP supports Jervis Bay Lowlands Shrub/Grass Dry Forest. The canopy attains 30 metres in height. There are extensive stands of Swamp Paperbark and Paperbarks along minor drainage lines and extensive stands of Sawsedge *Gahnia sieberiana* in the upper catchment of Coonemia Creek. In the lower catchment of this creek there are several freshwater wetlands that cover several hectares. Stands of Swamp Paperbark and Sawsedge edge the wetlands and Lake Wollumboola. The farm dams support Cumbungi and Spikerush *Eleocharis* sp.

The survey area at Greenwell Point is associated with three farm dams and two constructed shallows located on the edge of the floodplain. The shallows and one dam were designed to be ephemeral with the intent of catering for the breeding requirements of *L. aurea*. The dams support stands of Cumbungi and adjoin a grove of planted Swamp Oak that is 10m in height. Two dams supported a population of Plague Minnow and eels (as evidenced by dip netting and excavation work). The other dams/shallows were at times dry or fish free (by visual inspection). The site has been fenced to exclude domestic grazing animals. To the west, the land is cleared and grazed by cattle. The water level in the dams varied in response to rainfall and during extended periods of below average rainfall dry out.

The survey area at Culburra was located around the northern edge of Lake Wollomboola between East Crescent and the Culburra Retirement Village. The habitat included dams, Cumbungi-lined drains and ephemeral ponds behind a dunal swale beside the lake. The vegetation within this swale includes Twig-rush *Baumea juncea*, the sedge *Cyperus polystachyos*, Marsh Clubrush *Bolboschoenus caldwellii* and Swampweed *Selliera radicans*. Between the swale and the drainage lines were dense stands of Swamp Paperbark.

The survey along the Princes Highway included areas of Spotted Gum, Grey Ironbark, Stringybark and Red Bloodwood forest. The tributary of Browns Creek and other low lying and poorly drained areas had Woollybutt and the Paperbark *Melaleuca styphelioides* and *M. linariifolia*. The vegetation beside the section of Browns Creek and the dam supported stands of Cumbungi and Spikerush.

Frog surveys

Opportunistic and targeted surveys at Greenwell Point were undertaken from 1998 to 2014 for a total of 203 times. These surveys were mostly diurnal and were not time constrained. Searches involved walking slowly around or within the stands of Cumbungi during the day to observe basking frogs and were carried out mainly between September and April (Table 1). Diurnal searches for basking frogs in the Culburra area were conducted around the edge of lake Wollumboola and environs from 1997 to 2014 (Table 1). Surveys at the dams in Currambene SF were also from 1997 to 2014 (Table 1). These surveys were conducted by the author, and several other persons including residents and landowners. A groundsman (A. Parsons) undertook searches within the retirement village during his work activities and the data provided in Table 1 is a subset of the search effort.

Systematic and targeted surveys for *L. aurea* in Brundee Swamp NR, Saltwater Swamp NR and Worrigee NR were

Table 1. Number of Green and Golden Bell Frogs (average) observed per month at Greenwell Point, Culburra and Currambene SF

Location	Date	No. surveys	No. Bell Frogs	Comment
Greenwell Point	January 1998	8	2-16 (8.1)	Adults, more seen on sunny days
Greenwell Point	February 1998	6	0-16 (8)	Adults
Greenwell Point	September 1999	8	1-12 (5.5)	Adults and juveniles
Greenwell Point	October 1999	6	1-25 (18)	Adults and juveniles
Greenwell Point	November 1999	5	15-35 (22.4)	Mostly juveniles
Greenwell Point	December 1999	1	20	Mostly juveniles
Greenwell Point	January 2000	3	19-27 (22)	Adults
Greenwell Point	February 2000	5	13-30 (22.6)	Adults
Greenwell Point	March 2000	4	15-30 (23.5)	Adults and juveniles
Greenwell Point	April 2000	2	8-21 (14.5)	Adults and juveniles
Greenwell Point	May 2000	1	0	
Greenwell Point	September 2000	3	2-5 (3)	Adults and juveniles
Greenwell Point	October 2000	3	3-8 (5.7)	Adults and juveniles
Greenwell Point	November 2000	5	6-13 (9)	Adults and juveniles
Greenwell Point	December 2000	1	0	
Greenwell Point	March 2001	2	4-5 (4.5)	
Greenwell Point	November 2001	1	2	Adults
Greenwell Point	January 2002	1	0	
Greenwell Point	November 2002	8	5-12 (6.9)	Adults and juveniles
Greenwell Point	December 2002	4	5-10 (7)	Adults and juveniles
Greenwell Point	January 2003	5	4-9 (6)	Adults and juveniles
Greenwell Point	February 2003	2	7-8 (7.5)	
Greenwell Point	March 2003	2	0	
Greenwell Point	February 2004	1	1	Adult
Greenwell Point	March 2004	3	1-5 (3)	Adults and juveniles
Greenwell Point	October 2004	3	1-5 (2.3)	Adults and juveniles
Greenwell Point	November 2004	1	1	
Greenwell Point	December 2004	1	3	
Greenwell Point	January 2005	6	1-28 (14)	Adults and juveniles
Greenwell Point	February 2005	3	9-16 (15)	Adults and juveniles
Greenwell Point	March 2005	3	3-17 (11.3)	Adults and juveniles
Greenwell Point	April 2005	2	0-2 (1)	
Greenwell Point	May 2005	1	3	
Greenwell Point	October 2005	4	0-9 (4.3)	Adults and juveniles
Greenwell Point	November 2005	12	2-22 (12)	Adults and juveniles
Greenwell Point	December 2005	3	4-13 (9.3)	Adults and juveniles
Greenwell Point	January 2006	2	2	
Greenwell Point	February 2006	3	0-4 (2)	
Greenwell Point	March 2006	4	2-6 (3.8)	Adults and juveniles
Greenwell Point	April 2006	1	0	
Greenwell Point	January 2007	1	0	
Greenwell Point	February 2007	1	3	
Greenwell Point	March 2007	1	1	Adult male calling
Greenwell Point	November 2007	3	4-5 (4.3)	Adults
Greenwell Point	December 2007	9	0-4 (1.2)	Adults
Greenwell Point	January 2008	4	0-7 (3.8)	
Greenwell Point	February 2008	1	2	

Location	Date	No. surveys	No. Bell Frogs	Comment
Greenwell Point	March 2008	2	5-7 (6)	Adults
Greenwell Point	April 2008	4	4-34 (24)	Mostly metamorphlings
Greenwell Point	May 2008	1	13	Adults
Greenwell Point	July 2008	2	0	
Greenwell Point	October 2008	1	11	Four adults and seven juveniles
Greenwell Point	November 2008	4	6-59 (35.3)	Mostly juveniles
Greenwell Point	December 2008	2	20-52 (36)	
Greenwell Point	January 2009	3	0-3 (1.3)	Ponds dry
Greenwell Point	February 2009	3	16-24 (20)	Rain
Greenwell Point	March 2009	2	0-2 (1)	
Greenwell Point	April 2009	2	1-2 (1.5)	
Greenwell Point	May 2009	1	2	
Greenwell Point	July 2009	1	0	
Greenwell Point	September 2009	1	0	
Greenwell Point	October 2009	1	2	
Greenwell Point	August 2012	1	0	
Greenwell Point	December 2012	4	1-5 (2.5)	
Greenwell Point	January 2013	1	0	
Greenwell Point	February 2013	1	4	Three adults, one subadult
Greenwell Point	March 2013	1	1	
Greenwell Point	March 2014	1	3	Adults
Culburra Beach	Sep. 1992 — May 1993		1	Individual beside Lake Wollumboola
Culburra Beach	Sep. 1995 — May 1996	many	1000s	Metamorphlings along Lake Wollumboola shore east of Sheepwash Creek and East Crescent drains.
Culburra	April 1996	many	30-40	Adults & juvs. at retirement village ponds
Culburra Beach	April 1996	many	30	Wattle Corner Creek, Lake Wollumboola
Culburra	September 1996	1	4	Adults at retirement village ponds
Culburra	December 1997	1	13	All adults retirement village ponds, Bowling club pond and East Crescent drains
Culburra	January 1998		2	All adults at retirement village ponds
Culburra	August 1998		2	Adults at East Crescent drains
Culburra	Nov. 98-Jan. 99		3	All at retirement village ponds
Culburra Beach	April 2002	several	20-24	Adults and juveniles beside Lake Wollumboola shore
Culburra Beach	May 2002	many	30	Along Lake Wollumboola shore
Culburra	Nov. 2000 — March 2014		0	None detected at retirement village ponds
Culburra Beach	April 2011	1	1	Adult female on East Crescent frog pond
Culburra Beach	May 2011		2	Adults in drainage line Sheepwash Creek
Culburra Beach	April 2012		2	Adults in drainage line Sheepwash Creek
Culburra Beach	February 2014	1	0	Surveyed East Crescent drains, retirement village and Bowling Club
Currambene SF	January 1997	1	37	Adults
Currambene SF	December 1997	3	0-3	Adults
Currambene SF	March 1998	1	0	
Currambene SF	May 1998	1	2	Adults

Location	Date	No. surveys	No. Bell Frogs	Comment
Currambene SF	August 1998	1	1	
Currambene SF	October 1998	1	0	
Currambene SF	Match 1999	1	0	
Currambene SF	November 2000	1	1	Juvenile
Currambene SF	January 2007	1	0	
Currambene SF	April 2008	1	0	
Currambene SF	March 2011	1	5	
Currambene SF	February 2013	1	14	Adults plus subadults
Currambene SF	February 2014	1	0	

conducted from 2007 to 2014 (DECC 2007, Gaia Research 2008a and b, 2009a and b, 2010a, 2011, 2014) (Tables 2 and 3). The systematic surveys consisted of nocturnal searches spotlighting approximately 0.5 ha within select areas for 30 min each. In Brundee Swamp NR searches were conducted within discrete areas while at Saltwater Swamp NR and Worrigee NR they were along approximately 250 m of creeklines. Spotlighting was done with the aid of 50 watt/12 volt or 170-210 lumen LED spotlights. A single person usually conducted surveys and if a second person was present they did not record sightings.

Surveys were often initiated the night after intense bouts of summer rain to coincide with conditions that would stimulate breeding activity in frogs. A subset of three of the above sites (in Brundee NR) was resurveyed (Table 2) because *L. aurea* had been detected calling in the initial surveys.

Diurnal surveys were also conducted at 210 sites between 3 January 2011 and 1 April 2011, 96 sites between 31 January 2013 and 4 March 2013 and 221 sites between 5 February and 6 March 2014 over the broader area including freehold land, reserves and Currambene SF. Although the bulk of the surveys involved observations of basking frogs, detections were made of calling *L. aurea*. Surveys conducted on 11 January 2011 were done after approximately 70 mm rain had fallen. The weather at that time was warm, still and overcast. *Litoria aurea* began calling that day, better enabling detection of frogs and breeding sites.

A habitat assessment of 155 sites was undertaken. This included details of aquatic plants, presence/absence of exotic species of fish, disturbance and an estimation of *L. aurea* present. The assessment criteria were based on those developed for a previous survey of the species (Daly and Senior 2003) and detailed in Table 4. At several sites the number of frogs heard calling were a distance from the survey reference location, often on adjacent freehold land. The location of each site was recorded using a global positioning system (GPS) (projection in Geocentric datum of Australia 94 in Zone 56) and in most cases a photographic record was taken.

Several targeted surveys were conducted on land slated for development within the Brundee Swamp catchment. For one development approximately one hectare required removal of Swamp Paperbark. In this situation the Swamp Paperbark was slashed while two surveyors walked ahead of the machine and captured *L. aurea*. Frogs were held in a plastic container and released adjacent to the site in an area of Swamp Paperbark that was to be retained.

Table 2. Number of each species of frog detected at select survey sites during each 30min. nocturnal survey

Notes: *Litoria aurea* = La, *Litoria caerulea* = Lc, *Litoria dentata* = Ld, *Litoria jervisiensis* = Lj, *Litoria peroni* = Lp, *Litoria verreauxii* = Lv, *Crinia signifera* = Cs, *Limnodynastes dumerilii* = Lx, *Limnodynastes peronii* = Lz, Pb = *Pseudophryne bibronii*. The numbers separated by colons represent the number of frogs detected at each survey event.

Site name	Survey dates	La	Lc	Ld	Lj	Lp	Lv	Cs	Lx	Lz	Pb	Total species
Brundee 1	15.2.07 & 1.3.07	-	-	-	-	-	-	-	-	3: 6	0: 4	1: 2
Brundee 2	15.2.07, 1.3.07, 14.2.08 & 4.2.09	0: 5: 1: 15	0: 0: 1: 0	4: 35: 2: 0	-	0: 3: 5: 0	0: 0: 4: 0	0: 2: 12: 0	0: 5: 1: 0	0: 10: 25: 1	-	1: 6: 8: 2
Brundee 3	1.3.07 & 23.2.09	0: 2	-	35: 0	1: 0	1: 0	1: 1	5: 0	-	40: 2	-	6: 5
Brundee 4	5.2.10	50	4	20		10	1	1		10		7
Saltwater Swamp	11.3.09	3	-	-	-	-	-	-	-	-	-	1
Rotten Ck	27.1.09	3	-	-	-	-	-	-	-	25	1	3
Worrigee NR near Isa Rd	5.2.09	6	-	1	-	-	-	-	-	13	-	3
Worrigee NR southern boundary	19.2.09	3	-	-	-	-	-	3	-	6	8	4
Greenwell Point	1.12.05 & 28.12.07	4: 2	1: 0	20: 0	-	20: 10	-	0: 2	-	40: 2	-	4:4
Total		**96**	**6**	**117**	**1**	**59**	**7**	**27**	**6**	**195**	**13**	**4:4**

Table 3. Number of *L. aurea* detected during surveys in 2011 and 2014 over the Crookhaven River floodplain.

Notes: Surveys conducted between 3.1.11-1.4.11 and 6.2.14-6.3.14. All frogs were observed in the 2013 and 2014 surveys.

Site	Year 2011			Year 2013		Year 2014	
	No. sites	No. frogs detected	Comment	No. sites	No. frogs detected	No. sites	No. frogs detected
Almond Grove, Worrigee	-	-		0	-	1	2
Albatross Rd	2	1	Observed	2	0	2	0
Antares Cl Res - Kameruka Csnt Res.	3	2-5	Observed	0	-	3	0
Apperleys Ln	4	0-10	Calling	0	-	4	0
Arunta Close	1	0		0	-	0	-
Booligal Rd	1	0		1	0	1	0
Bournes Ln	6	0-40	Calling	3	0	6	0
Brundee Swamp NR	1	4	Observed	2	3	4	0
Brundee Swamp freehold	-	-		1	0	6	2
Burton Park	1	0		0	-	0	-
Callala Bay	3	0-2	Observed	1	0	3	0
Callala Beach	3	0		1	0	3	0
Callala Sewerage Treatment Works	2	1	Observed	2	3	2	0
Campbell Place Reserve, Worrigee	4	0		0	-	4	0
Carrington Park Estate, Worrigee	6	0-1	Observed	2	0	6	0
Comerong Island Rd	8	0		0	-	8	0
Culburra: Club, Retirement village etc	5	0-2	Observed	5	0	5	0
Culburra East Crescent culverts	6	0-1	Observed	5	0	6	0
Culburra Ln – Coonemia Rd	3	0		1	0	3	0
Currambene SF Butterfly Rd	2	2-5	Observed	2	7-14	2	0
Depot Farm Reserve, Nowra	1	0		0	-	0	-
Dryden Close Reserve Worrigee	2	0-1	Observed	0	-	2	0
East Nowra Drainage Reserve	6	0-5	Observed	0	-	6	0
Elderberry Avenue Worrigee	1	0		0	0	1	0
Equestrian centre, Worrigee	2	0-10	Observed	1	0	2	0
Fish farm Falls Creek	10	0-1	Observed	10	0	10	0
Flat Rock Dam	1	0		0	-	1	0
Flinders Rd - Nowra Ck	5	0-1	Observed	4	0	5	0
Greenwell Point Rd	9	0-1	Observed	0	-	9	0
Greenwell Point	5			5	4	5	3
Isa Rd, Worrigee	1	7	Observed	1	0	1	0
Jervis Bay National Park - Coonemia Ck	3	0-1	Observed	0	-	0	-
Jervis Bay National Park dams	4	1-4	Observed	4	0	4	0
Jindy Andy Lane	8	0-30	Most calling	0	-	8	0
Journal St Reserve	8	0-1	Observed	0	-	8	0
Liberty Rd (Basil St), Worrigee	3	3-35	Observed	1	1	3	0
Lightwood Rd	1	0		0	-	0	-

Lyrebird Sports Park, East Nowra	5	0-1	Observed	5	0	5	0
Mayfield Rd, Mayfield	5	0-10	Calling	0	-	5	0
Millbank Rd, Mayfield	8	0-3	Observed	0	-	8	0
Mountain Ash walkway	1	6	Observed	0	-	1	0
Nowra Ck, south Nowra	6	0-1	Observed	0	-	6	0
Nowra Racecourse	2	0	Observed	0	-	0	-
Nowra Sewage Treatment, Terara	3	2	Observed	0	-	3	1
Nowra SF Bid Bid Ck, Georges Creek	3	1-3	Observed	1	0	1	2
Old Southern Rd, Worrigee	4	0-3	Observed	0	-	4	0
Pipeline Rd	1	0		0	-	0	-
Princes Hghy south Nowra	1	14	Observed	1	0	1	0
Putt Put golf course, Worrigee	1	7	Observed	1	2	1	0
Pyree Lane	5	0		3	0	5	0
Quinns Lane, south Nowra	3	0-2	Observed	1	0	3	0
Ratcliff Park and environs	4	1-2	Observed	4	0	4	0
Rayleigh Dr Reserve	1	0		0	-	1	0
Salisbury Dr Reserve, East Nowra	3	0-1	Observed	3	0	3	0
Shoalhaven High - reserve	1	0		0	-	1	0
Smiths Lane	5	0-30	Calling	0	-	5	0
Sophia Rd	2	0-2	Observed	2	0	2	0
Springbank Rd – Mayfield Rd	4	0-15	Calling	0	-	4	0
St James Crescent Reserve and walkway	2	0		0	-	2	0
Ballina Rd south Nowra	2	2-24	Observed	0	-	2	0
Wallace Park	4	0-1	Observed	4	0	4	0
Warra Warra Rd	2	1-1	Observed	2	0	2	0
Worrigee Nature Reserve - Rotten Creek	5	1-19	Observed	7	2-5	5	1-4
Worrigee Rd	10	0-22	Observed	8	2	10	0
Totals	**225**	**c.**		**96**	**57**	**222**	**17**

The DECC (2008) *Hygiene Protocol for the Control of Disease in Frogs* was followed. Equipment such as boots was thoroughly disinfected with dilute anti-fungicide benzalkonium chloride, prior to surveys.

Results

Greenwell Point

Over 17 years the number of *L. aurea* detected at this survey site varied from 0-59 (maximum of 27 adults). Metamorphlings and tadpoles were observed, confirming breeding activity during summer in 1999, 2000, 2001, 2005, 2007 and 2008. During *el nino* years of unseasonally low spring and summer rainfall, such as in 2009 and 2014 the ponds were either dry or had reduced water levels and breeding was not recorded with less than ten animals observed. In two dams Plague Minnow and Eels *Anguilla australis* were detected. During floods the dams and ponds were engulfed by water that covered several hectares facilitating dispersal of Plague Minnow and Eels. *L. aurea* was recorded breeding in ephemeral shallows that were fish-free during floods.

Culburra

In 1995 hundreds if not thousands of juvenile *L. aurea* were observed beside East Crescent around the edge of Lake Wollomboola. A breeding site was located in a swale on the edge of the lake, that after sufficient rain filled with fresh water, but was fish free. Frogs were regularly seen around East Crescent and ponds nearby at a bowling club and retirement village, indicating breeding at various times until April 2002. Since then the number of frogs has declined (F. Bray: pers. comm.) and no animals had been reported from May 2003 until the current surveys on 22 March 2011 (Table 1). Diurnal inspections for several hours on that day revealed an adult and two subadult frogs near Lake Wollomboola (bowling club dams and a drainage line in East Crescent). Frogs have not been detected at Culburra since that time.

Brundee Swamp NR

From January 2001 to January 2007 the Shoalhaven experienced a period of reduced rainfall (Bureau of Meteorology Nowra AWS station 068072). The survey sites were either dry or reduced to small isolated pools of

Table 4. Data collected for site assessments.

Character	Details
Site specific code reference	Name of street, creek and / or wetland
Date	
Names of person/s assessing	
Location description	Brief description of how to access site
Topographic map details	1:25000 map code, name and zone
Location details	Grid reference/s and altitude
Tenure	Freehold, National Park, State Forest, local government area
Soil	Surface soil broad features – clay, sand, depth of soil
Water body	Ephemeral or permanent
Occupancy	Bell Frogs present or absent
Disturbance	Grazing, weeds, mowing
Surrounding vegetation	Canopy, and understory species (emergent aquatic plants)and approximate height
Point Data	Additional grid references for any subsites and number of Bell Frogs seen or heard
Threatening processes	Presence of Plague Minnow, eels, grazing, mowing, pollution or other processes

water as of January 2007. The intensity of the dryness was such that breeding activity of many species of amphibians was much reduced. Significant (287mm) rain fell during late February 2007 (Table 5) and was sufficient to fill the wetlands; this preceded high levels of frog breeding activity.

A diurnal search of the wetland mid February 2007 revealed that it was reduced to a few isolated small pools. In March 2007, frog searches were conducted on the eastern and western side of the reserve. No *L. aurea* were found on the eastern side of the reserve, but five males were heard calling at night from a flooded area on the western edge of the reserve. This area was to become the focus for further surveys and the following observations are from the western portion of the reserve.

Diurnal inspections revealed that the swamp dried later during 2007 and was dry during January 2008. On the 5 February 2008, 113 mm of rain fell and the swamp filled to a level to stimulate breeding activity for frogs. Nocturnal surveys on 14 February 2008 detected one *L. aurea* and a very large number of tadpoles of many species of frog were observed, indicating a significant breeding event had occurred after the rain filled the wetland to a depth of approximately 250 mm. No *Gambusia* were detected within that section of the wetland at that time, but were later observed in a drainage channel on the southern edge of the reserve (DECC 2007).

Additional rain fell during February 2008 and a total of 251mm recorded. During a 73 minute diurnal search over a few hectares on 2 April 2008, 86 metamorphling *L. aurea* were observed. The metamorphlings were mostly perched about a metre above the ground in Swamp Paperbark but some were on the ground near water (Figure 2). Further searches revealed tadpoles and metamorphlings at another two sites in the reserve. The wetland had dried and only small residual pools of water remained. Plague Minnow were observed during that survey at one site and some were found dead with *L. aurea* tadpoles in isolated pools (Figure 3). These observations indicated that there had been a major breeding event during January 2008.

Two 30-minute systematic surveys were conducted in

Table 5. Data courtesy Bureau of Meteorology Nowra RAN Air Station AWS station 068072. Note long term average for Nowra is 1112 mm.

Month	1971-2000	2007	2008	2009	2010	2011	2012	2013	2014
January	95	14	67	28	56	82	53	131	35
February	121	287	251	75	180	65	180	170	12
March	125	90	42	33	56	166	320	49	270
April	102	48	44	94	35	67	89	117	39
May	88	18	8	27	90	52	18	70	17
June	109	323	84	22	90	79	104	338	75
July	52	54	49	18	63	142	33	47	3
August	76	47	60	10	30	52	8	8	
September	67	26	58	16	30	55	19	98	
October	88	12	94	127	73	89	51	11	
November	89	115	61	2	151	81	43	130	
December	70	78	79	105	157	83	27	63	
Annual totals	**1082**	**1112**	**897**	**557**	**1011**	**1013**	**945**	**1232**	

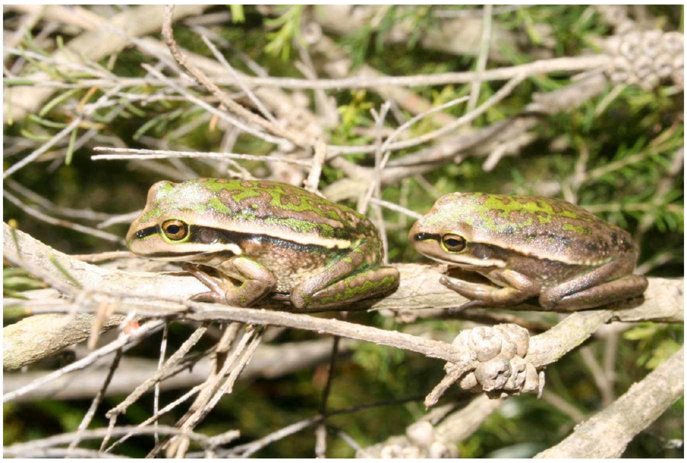

Figure 2 Metamorphling Bell Frogs on Swamp Paperbark at Brundee Swamp

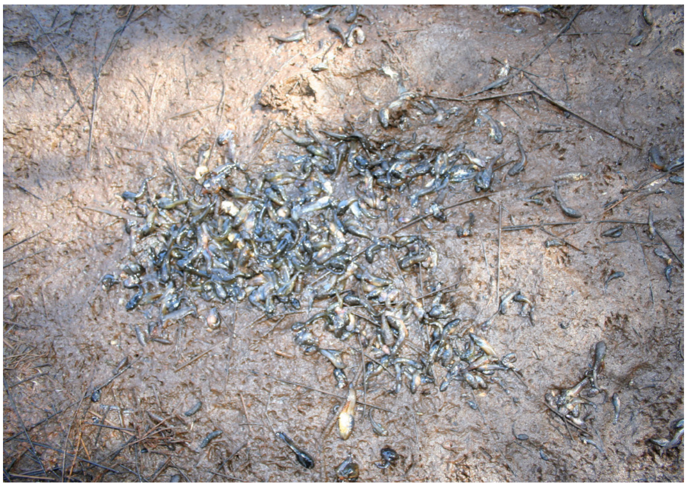

Figure 3 Bell Frog tadpoles and Plague Minnow stranded by receding water at Brundee Swamp NR

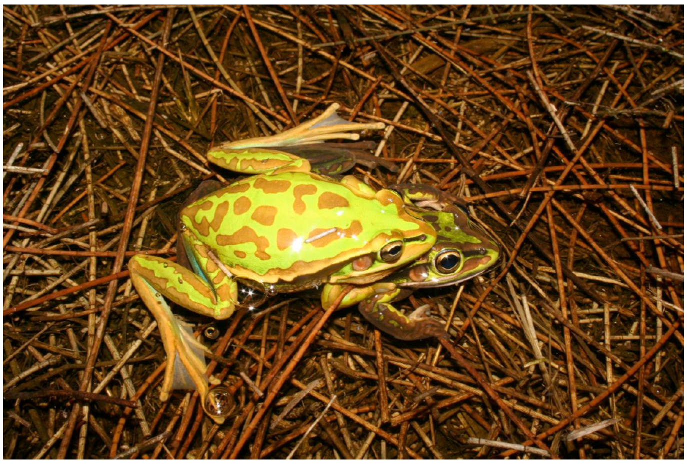

Figure 4 Amplecting Bell Frogs at Brundee Swamp NP

February 2009. During that time 14 sub-adult *L. aurea* were observed but no adults were heard calling. There was open water in the areas surveyed, but the depth was relatively low (less than 100mm). There had only been 28 mm rain in January and 75 mm in February 2009.

A diurnal survey on 5 February 2010 revealed that the majority of the wetland did not have free water. However, four *L. aurea* were heard calling some 400 m metres from the initial site and were observed beside a pond some 200 m away. From this location another chorus of frogs could be heard a further 200 m away. When this area was inspected approximately 50 males were found congregated at another shallow expanse of water (Table 2). During searches that night eleven amplecting pairs (Figure 4) were observed. During February 2010 a total of 180 mm rain fell and the wetland flooded.

Subsequent searches of the above areas on 24 March 2010 revealed a large number of tadpoles and metamorphling frogs. During a search lasting approximately 15 min thousands of metamorphling Bleating Tree Frogs *Litoria dentata* and about 20 metamorphling *L. aurea* were observed. The large number of animals meant that care had to be taken when walking about the site as frogs were densely distributed in the grass and on and under the low ground cover vegetation. By April 2010, uncountable numbers of metamorphling *L. aurea* were present across the landscape from the Brundee and Terara wetlands (M. Bennett, T. Russell, T. Cochrane, P. Craven, L. Mitchell: pers. comm., pers. obs.), enough to stimulate media attention (Daily Telegraph 3 May 2010). By all accounts the number of metamorphling frogs was conservatively in the tens of thousands.

On 16 November 2010 a diurnal survey of Brundee Swamp NR revealed a sub-adult *L. aurea* and one frog was heard calling from a flooded paddock nearby on freehold land. At the juncture where Rotten Creek enters the wetland, a further ten sub-adult *L. aurea* were observed. Plague Minnow were abundant at this site.

A diurnal survey was conducted on 2 December 2010. One adult was observed and approximately fifteen were heard calling in an area flooded with about 200 mm of water. The frogs were calling from under Swamp Paperbark on the edge of an area that otherwise lacked shrubs or trees. Late Gosner stage (Stage 26) *L. aurea* tadpoles and Plague Minnow were observed throughout the wetland at that time.

On 10 January 2011 a nocturnal survey was conducted at Brundee Swamp NR. Four juvenile *L. aurea* were observed in the wetland, but hundreds were observed on the roads within a few kilometres of the reserve, many had died as a result of collisions with vehicles. During a diurnal survey conducted on 23 March 2011, 67 adult and subadult *L. aurea* were observed in a 1 km transect over 2.5 hours in the south-western sector of the reserve (P. Craven pers. comm.).

On 26 January 2012, 4, 5 and 9 February 2012 diurnal and nocturnal surveys were conducted at Brundee Swamp. The breeding sites within the reserve lacked open water, but *L. aurea* was detected on adjacent land. On 4 February 2012, approximately 12 males called periodically during the day at two sites, one was in a cow paddock. The water at these sites was about 50 mm deep. The frogs called about every 3 min and did not respond to imitations of the calls. Visual assessments indicated both breeding sites appeared to have low densities of *Gambusia* as opposed to adjacent drainage channels where large populations of this fish was observed. Nocturnal and diurnal surveys on 2 and 5 March 2014 respectively revealed the wetland was dry. No *L. aurea* were detected.

Saltwater Swamp NR and environs

On the 11 March 2009 a single 30 min spotlight search along the eastern un-named creek detected three adult *L. aurea*. Prior to this survey the species had not been recorded in this reserve. Diurnal searches conducted along this creekline from 24-26 February 2009 and in a much broader area of the wetland (several kilometres) on 10 March 2009 failed to detect *L. aurea*.

On 3 December 2010 a diurnal search was conducted along the western perimeter of Saltwater Swamp NR. The search transect was approximately 2 km. No *L. aurea* were detected and the reserve was flooded making access difficult. *L. aurea* were observed close to Saltwater Swamp NR in March 2011 at two dams in Currambene State Forest and beside a small creek on land managed by the local council.

I monitored *L. aurea* at the dams in Currambene SF, within the catchment of Saltwater Swamp NP, since 1997. To date, a maximum of 56 adults have been seen at this site at any one time (Bower and Goldingay 1998). No *L. aurea* were detected in 2007 and 2008 and no breeding, as evidenced by tadpoles or recently metamorphed animals, were recorded at these sites at any time.

Worrigee NR

Diurnal and nocturnal streamside surveys were conducted at three sites in Worrigee NR on 27 January, 5 February and 19 February 2009. *Litoria aurea* were observed at all sites, 3 at Rotten Creek (dry at the time of survey), six at the drainage line south of Isa Road and three at the drainage line near the boundary between Worrigee NR and the Worrigee NR extension.

Diurnal amphibian surveys were conducted on 24 February 2011 along the eastern drainage lines in the north-eastern sector of Worrigee NR. Forty adult and sub-adult *L. aurea* were observed mostly in stands of Sawsedge. Repeat surveys of this area on 6 February 2014 revealed one adult frog. Surveys of a Cumbungi filled drainage line in the north-western sector of Worrigee NR on the same day revealed the presence of four adult *L. aurea*.

Surveys in Nowra SF, to the south of Worrigee NR, also revealed adult *L. aurea* in drainage lines, perched on Saw-sedge. Three frogs were observed on 25 February 2012 and two on 5 March 2014. These sites were in forest partially shaded by *E. longifolia* and *E. robusta*.

Jervis Bay NP

Diurnal searches were conducted on 16 February 2011, 22 March 2011 and 6 March 2014. On 16 February 2011 *L. aurea* were observed in all four ponds in the Copper Cup Point area. This was significant, as the species was not detected at these sites in March 2009 (Gaia Research 2009b) and previously not recorded from the park. Searches at these sites on 6 March 2013 and 6 March 2014 failed to detected any *L. aurea*. Plague Minnow were observed in two of the ponds, which hold permanent water. On 22 March 2011 an adult *L. aurea* was observed beside Coonemia Creek, basking on Saw-sedge. Two searches at the wetland in the lower reaches of Coonemia Creek failed to detect *L. aurea*.

Observations outside the reserve system in the Crookhaven floodplain

Terara Swamp

On the 25 March 2010 diurnal searches were conducted on freehold land that constitutes a portion of Terara Swamp. Approximately 100 metamorphling *L. aurea* plus tadpoles were observed in 30 min (Gaia Research 2010a) along a minor drainage channel and a flooded area next to the main drainage channel. The landowner stated that a few days before the survey that he had been driving in an adjacent paddock (approximately 1 km from the breeding site) and noticed what he thought were thousands of grasshoppers. Only when he stopped the vehicle did he realise that the animals were metamorphling *L. aurea* (T. Cochrane pers. comm.). The drainage channel and a section of the flooded area also supported *Gambusia*.

Crookhaven floodplain and beyond

Surveys for *L. aurea* were conducted from 16 November 2010 – 1 April 2011 at 230 sites within the Crookhaven floodplain. Diurnal surveys involved searches of emergent aquatic vegetation, especially *Typha* spp. and Saw-sedge while the nocturnal search involved the use of a 50 watt/12 volt spotlight. A total of 278 *L. aurea* were observed and a further 185 were heard calling on 11 January 2011. The calling frogs were tracked down and ten potential breeding sites were noted on freehold land. From 7 January 2011 to 25 January 2011 during clearing of Swamp Paperbark in the catchment of Brundee Swamp a total of 376 frogs were captured and relocated. Frogs were sub-adults being 45-55 mm snout-vent. In one day, 111 frogs were found in an area of approximately 100 x 300 m.

By March 2011, the Crookhaven *L. aurea* population was detected as far north as the Shoalhaven River, south to Currambene Creek, east to Culburra and west to Albatross Road-Nowra Hill. There was also a few records south-east of Currambene Creek (Woollamia) but it was not determined if frogs had spread south of the creek or these observations represent a separate population.

The highest altitude that frogs were found at was 100 m AHD (M. Smith pers. comm.). Bell frogs were found in several catchments outside the Crookhaven River where they had not been recorded for many years. The apparent spread of the frogs appeared to be linked to a set of favourable summer rainfall events from 2007 to 2011.

By March 2013, the Crookhaven *L. aurea* population had declined in abundance (total of 57 animals seen during that sampling period Table 3) and distribution. Animals were observed as far west as the Princes Highway, east to Greenwell Point but not west of Coonemia Rd (Culburra or Jervis Bay NP), north to Worrigee and south to Butterfly Rd in Currambene SF (debris from a severe windstorm prevented some northern surveys at Terara). All frogs were either adult or subadult. A photograph supplied to the author in May 2013 indicated *L. aurea* persisted south of Currambene Creek in the Woollamia area.

Surveys conducted during February and March 2014 within the broader Crookhaven area indicated that *L. aurea* had further declined in abundance with a possible 17 adult frogs observed (Table 3). Animals were observed as far west as Worrigee NR, east to Greenwell Point but not west of Coonemia Rd (Culburra or Jervis Bay NP), north to Terara and south to Charcoal Rd in Nowra SF (Gaia Research 2014).

Other species of frog

Other species detected during the surveys were the Green Tree Frog *Litoria caerulea*, Bleating Tree Frog *L. dentata*, Dwarf Tree frog *L. fallax*, Jervis Bay Tree Frog *L. jervisiensis*, Verreaux's Tree Frog *L. verreauxii*, Common Eastern Froglet *Crinia signifera*, Pobblebonk *Limnodynastes dumerilii* (*insularis*), Striped Marsh Frog *Limnodynastes peroni* and Bibron's Toadlet *Pseudophryne bibronii*. The most abundant species detected during systematic searches was *Limnodynastes peroni*, while the most common tree frogs were *L. dentata* and *L. aurea* (Table 3). The Dwarf Tree Frog was only detected at Brundee Swamp in 2012 and by February 2013 had colonised Greenwell Point.

Threatening Processes - Plague Minnow and chytrid

Permanent populations of *Gambusia* exist in the steams and drainage channels throughout the Shoalhaven River - Crookhaven River floodplain and the catchment of Lake Wollumboola. Plague Minnow were observed to swim upstream during times of flood colonising sites that had previously been dry. However, due to the uneven topographic landforms all sites where *L. aurea* bred were either fish free or colonised by *Gambusia* after frogs had bred.

Skin swab samples were taken from four *L. aurea* at Brundee Swamp NR (Gaia Research 2008a) and adjacent freehold land in 2013 (Umwelt 2013). The samples were taken using the methods described by Kriger and Hero (2006) and analysed by CSIRO laboratory in Geelong Victoria and Newcastle Amphibian Research Group. The samples were analysed by Taqman real-time Polymerase Chain reaction (PCR) assay in triplicate (Boyle *et al.* 2004). Chytrid was absent from the few samples taken in 2008 but present in two of the 54 individuals tested in 2013. *Litoria aurea* found within Brundee Swamp have a low incidence of chytrid during summer.

Discussion

Population size: national and regional significance

The Crookhaven River floodplain population of *L. aurea* has waxed and waned since frogs were detected in Currambene SF (Braithwaite *et al.* 1988). At its peak, this may be one of the largest extant *L. aurea* populations in New South Wales with a conservative estimate totalling several thousand adult frogs. It may be no coincidence that the population expansion coincided with specific rainfall events that created many breeding sites that were fish-free. *Litoria aurea* is known to eat other species of frog (Pyke and White 2001) and the presence of hundreds of thousands of metamorphling *L. dentata* in 2010 may have provided a ready source of food for metamorphling *L. aurea* and hence aided in the survival of young frogs.

Based on these surveys, it would appear that the core breeding area for *L. aurea* in the south Shoalhaven floodplain is Brundee Swamp. Field surveys indicate frogs expanded their range in 2011 to colonise reserves, State Forests and freehold land approximately 4 km south-west and 11 km to the south-east of this wetland, to encompass the southern side of Currambene Creek, Coonemia Creek and Nowra Creek catchments. Surveys in 2013 and 2014 indicated a contraction of this range to approximately 6 km of Brundee Swamp. The population at Woollamia appears to be isolated.

The response of adult *L. aurea* to periods of sustained rainfall may be to disperse from dry-weather refuge sites in the catchment of Brundee Swamp to recently flooded areas for breeding. Breeding behaviour (calling males and amplecting animals) increased markedly with summer rain and higher temperatures being recorded in late December to early March (Tables 2-4). Thereafter, adult frogs appear to disperse and were most frequently observed along creeks that feed the wetland, in dams that support stands of Cumbungi, Saw-sedge and stands of Swamp Paperbark (Tables 2-4).

After metamorphosis juvenile frogs appear to stay within the wetlands for a short period and later disperse. The breeding sites at Greenwell Point and Culburra (and possibly Woollamia) are most likely outliers of the core Brundee swamp population and if the population wanes, these may become isolated and in the case of Culburra die out.

The history of the frogs at Culburra illustrates the point that the population can vary considerable over time. *Litoria aurea* were first noted at Culburra in early 1994 when hundreds of metamorphling *L. aurea* were observed beside open drains near East Crescent (K. Campbell; pers. comm.). Later surveys by the author found *L. aurea* breeding in an ephemeral swale beside East Crescent on the edge of Lake Wollomboola and a few frogs were found some 4 km to the west on a farm dam (Daly and Leonard 1996).

As a consequence of council slashing the drains, a study was done in 1999 to assess the population in relation to broader management prescriptions. During a capture-mark-recapture study a total of 32 adults were caught and a population size of 37-40 adult frogs estimated (Grenadier and Mahony 2000). Thereafter, the population appears to have waned and to have become locally extinct from May 2003 and did not reappear there until the next wave of dispersing animals recolonised the area in 2011.

The presence of outlier sites was "normal" up until 2010. But by 2011 *L. aurea* had dispersed and bred at a number of locations across the floodplain. The presence of *L. aurea* at recently occupied sites in 2011 may have been a result of suitable weather patterns creating chains of potential breeding and dispersal habitat across the floodplain.

The draft recovery plan (DEC 1995) indicated that the Culburra and Woollamia-Currambene Creek populations of *L. aurea* were separate but this study shows that after favourable seasons, the Crookhaven River key population encompasses these areas. If the population continued to expand it may recolonise other sites, including where the species has not been detected for many years, such as the Beecroft peninsula (Coyne *et al.* 1979) and Bherwerre peninsula (Daly 2000) on the northern and southern side of Jervis Bay. Unfortunately recent surveys indicate the population has waned, a result of inadequate rainfall during the breeding season and possibly mortality associated with chytrid.

Breeding habitat utilised by *Litoria aurea*

This study concurs with previous work that found *L. aurea* primarily breed in fish-free, unshaded, ephemeral, coastal wetlands that possess areas of sedgeland and swamps with emergent aquatic vegetation (DEC 2007a, b and c, Daly and Senior 2003, Daly *et al.* 2008, Pyke and White 2001). The fact that all breeding sites located in this study had ephemeral water is considered significant. When these sites fill after intense summer rain they are colonised by several species of frog. *Litoria aurea* has been found to abandon breeding sites, which support permanent water and Striped Marsh Frog *Limnodynastes peroni* tadpoles (G. Daly pers. obs.). The use of ephemeral ponds appears to favour survival of *L. aurea* tadpoles and adult frogs actively seek out such environments to breed. At times, some sites at Brundee Swamp were colonised by *Gambusia* after they filled to a certain level, but in the years where there was a large recruitment of tadpoles, fish were not present until after the tadpoles had attained a relatively large size. The combination of dense aquatic vegetation, size of tadpole and low population of fish are considered factors that contributed to the survival *L. aurea* tadpoles at this site.

Litoria aurea was found calling and breeding primarily in the shallows of water that ranged in depth from c. 25-300 mm. Some sites were grazed by cattle and had no emergent aquatic plants. At sites that lacked emergent plants calling frogs were very dark and difficult to observe. The dull colouration may have afforded the animals protection from predatory birds. *Litoria aurea* were also heard calling at the edge of mangroves *Avicennia marina* on the edge of the Crookhaven floodplain on Saltpan Creek. Other studies have recorded *L. aurea* breeding in semi-saline water (Daly *et al.* 2008) and the species has been recorded calling in mangrove areas at other locations (e.g. Homebush Bay and Kurnell). *Litoria aurea* tadpoles can tolerate salinity up to 4 % seawater (Christy and Dickman 2002).

Males were detected calling during the day on 5 February 2010 and 11 January 2011. This is unusual as *L. aurea* normally form breeding choruses at night (Pyke and White 2001). At Brundee Swamp, approximately 50 males were concentrated into a relatively small area (40 x 40 m) and were very active, competing for prime calling sites. The competitive behaviour of the males was similar to that observed by Harrison (1922-5), that is "frogs play about the surface of the water, swimming and floating, the males calling at intervals, and pursuing and trying to embrace any frog that comes near them". Hearing *L. aurea* call during the day allowed detection of new breeding sites on freehold land and other sites where access may have been difficult (Table 4).

Dispersal and refuge habitat utilised by *Litoria aurea*

Litoria aurea dispersed from Brundee Swamp and Terara Swamp across highly modified environments including pasture, roads and urban areas. Recently metamorphosed frogs moved over large areas of exotic grassland that had little cover. After the initial dispersal, frogs were associated with creeklines, soaks and dams. In Worrigee NR and Currambene SF frogs were often found in stands of Saw-sedge, a species of plant that had not previously been documented to provide refuge habitat for *L. aurea*.

Frogs were observed to over-winter beside fish ponds in urban areas and in small dams that supported dense stands of Cumbungi. *Litoria aurea* were also found in man-made structures such as covered concrete sumps. A portion of the Crookhaven population over-winters in the urban area of Worrigee. The species is highly opportunistic and adaptable and these behaviours have aided its survival in coastal environments where human impacts are ongoing. However, the species has benefited by large areas of native vegetation being managed within the Reservation and State Forests systems.

Other species of frog

With the exception of *L. caerulea*, the species of frog (*Litoria dentata, Litoria jervisiensis, Litoria peroni, Litoria verreauxii, Crinia signifera, Limnodynastes peronii*) recorded sympatric with *L. aurea* are typical of those found in coastal wetlands on the south coast of NSW (Daly and Senior 2003). Current data indicates that the Shoalhaven local government area is the southern limit for *L. caerulea*, the species is uncommon and as a consequence of urban development separated from those north of Sydney. Brundee Swamp supports the largest population of *L. caerulea* known south of Sydney (G. Daly unpub. data) and this population experienced recruitment in 2010.

Data from these surveys suggest that the population of *L. dumerilii* in Brundee Swamp is relatively small with only a few animals detected. This species has been found on Beecroft Peninsula, some 20 km to the south-east and is the subspecies *insularis* (Daly 2000). *Litoria fallax* continues to expand its historic range to colonise the coastal plain of the Shoalhaven local government area.

Chytrid fungal pathogen

Frog chytrid *Bactrachochytrium dendrobatiodis* disease may be the key factor limiting recovery of *L. aurea* (Berger *et al.* 1999, Stockwell *et al.* 2008, Penman *et al.* 2008). Chytrid was present in a few frogs sampled from Brundee Swamp NR (Umwelt 2013) and frogs displaying symptoms of chytrid have been found several kilometres from the floodplain. The disease is implicated in the die off of frogs reported in August 2012 (Daly unpub. data). There is an accumulating body of evidence that *L. aurea* persists at sites where chytrid is mediated by a range of antifungal chemicals (Daly *et al.*, 2008; Osborne *et al.*, 2008; Threlfall *et al.*, 2008). The decline and contraction of the population by early 2013 suggests chytrid had caused the decline. The presence of chytrid infected sick and dead frogs along the Princes Highway implies this pathogen was the causal agent.

The expansion of the Crookhaven *L. aurea* population could be seen solely as a response to a series of rainfall events that has by chance benefited the species. This may be the case, but the increase in frog numbers raises the question why other nearby populations (i.e. Shoalhaven Heads) have not responded in a similar manner (Daly unpubl. data). During the current survey, *L. aurea* colonised new sites approximately seven kilometres from the floodplain that contain acid sulphate soils, which may help mediate chytrid. This colonisation appears to have been a temporary phenomenon. There is a need to assess the level of chytrid infection in this population over various seasons and locations to help determine why the frogs persist within certain confines.

Appropriate survey methods

Fauna surveys seek to quantify the number of animals at a particular location and time (NPWS 1997, DEC 2004). The problem for herpetologists is that frog activity is highly associated with season, temperature and rainfall. For *L. aurea*, a species that breeds in spring and summer (often after intense rain), surveys should coincide with periods of high activity. This study and others (Daly 1996) have illustrated that, even at known sites, breeding adults may only be found over a few nights before dispersing. Researchers need to coincide surveys with these specific events otherwise counts will under estimate the size of a population. I was fortunate to reside close to the study area and could undertake surveys at a limited number of sites when favourable conditions existed.

Part of the current survey used fixed time searches for frogs. These methods, modelled on those developed during the comprehensive regional assessment of forests in NSW, have provided the largest set of quantitative data of amphibians in south-eastern NSW (Daly *et al.* 2002, Daly 2006, Daly 2007, Daly and Craven 2007, Daly *et al.* 2008, Daly *et al.* 2009, Daly and Craven 2010). It is recommended that where possible researchers adopt these methods as a standard (Daly and Craven 2007). However, for *L. aurea*, the use of systematic methods is problematic because the habitat used may not be of adequate size to conduct fixed time transects. Hence, targeted searches, often conducted during the day, were able to provide presence-absence data, quantitative counts and detected the location of breeding sites. A combination of survey methods is required for monitoring to complement the behavioural traits of *L. aurea*.

Management

As a result of the Regional Forestry Agreement reserves such as Brundee Swamp, Saltwater Swamp and Worrigee, totalling some 640 ha of *L. aurea* habitat, came under the management of the NSW NPWS in 2001 (NPWS 2008). At that time the reserves were modelled as potential habitat for the frog, but it was not known how significant the sites were. The portion of Worrigee NR now within the reservation system was slated for urban development and this would have reduced *L. aurea* habitat directly by piping creeks and reducing vegetation cover and indirectly by increased mortality from domestic pets and moving vehicles. Currently there are 384 ha adjacent to Worrigee NR vested for gazettal. A management plan for the Crookhaven population of *L. aurea* was prepared by the author for the Department of Conservation (DEC 2008). Data on this population has expanded considerably over the last six years and the plan requires updating.

Outside the Reservation system the management of the Crookhaven population of *L. aurea* has been reactionary. There have been two referrals to the Commonwealth under the EPBC Act (1979) (Gaia Research 2010b and c). A review of the management of *L. aurea* in the area is currently being undertaken (Daly *et al.* in prep.). The present study indicates that potential breeding, refuge and dispersal habitat for *L. aurea* must be conserved over the entire landscape to facilitate persistence and possible recovery of a species that may be absent from an area for many years. The absence of frogs from a site for a time does not justify the dismissal of that site as potential habitat, nor does it justify the removal of habitat for the species.

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